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ABSTRACT

Students aged 10 to 17 years in a primary school and a secondary school in an industrial suburb of Melbourne, Australia, were observed as they worked at activities in both curriculum and non-curriculum areas using MITSI, a computer program, as a KBS (knowledge-based system) tool. Evaluations of the students' general abilities, computer abilities, and opinions and attitudes led to the conclusion that well-designed activities based on MITSI are very well received by learners and teachers, and can produce valuable learning outcomes. Vital considerations in planning to use MITSI are the characteristics of the system, the selection and design of learning activities, and the emphasis that is placed on general cognitive abilities. The key to good activities is the discussion and thinking they can spark, and this depends as much on the way they are presented and supported in the classroom as on the details of the computing. MITSI is a good tool for a broad range of information-handling activities, including using or building databases, exploring and expressing simple logical relationships among items, and organizing a body of knowledge and expressing it in a systematic and rule-bound way. Experience shows that it is more effective to allow beginning students to explore pre-written programs before extending them or building their own; the transition to writing programs and writing rules should be gradual. Structured worksheets that permit students to work at their own pace can free the teacher to provide individual assistance to those with special problems, and a wide range of activities add interest, allow users to explore MITSI more fully, and promote a richer range of general skills. Things to watch for include finding enough time, individual differences among students, being sure the computer is the best way to meet a particular educational goal, integrating computer work, looking for computer spin-offs, and being wary of sex-role stereotypes. (7 references) (MES)

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# Using MITSI as a KBS tool for learning

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For several years we have been observing children, aged 10 to 17 years, working at a wide variety of activities using MITSI as a KBS tool. Our aim has been to develop activities that work well in ordinary classrooms, and then to study the educational outcomes. In this paper we describe our conclusions about the design and use of MITSI activities with school students. The conclusions are based partly on our quantitative research, but largely on our classroom experience and the views expressed by teachers with whom we have worked closely.

We took as starting assumptions that we were interested in:
1. Promotion of, first, higher cognitive abilities, second, subject matter learning and, only third and incidentally, computer knowledge.
2. Working with unselected children in ordinary classrooms, who worked with their own, unselected teachers.
3. Working with children of the full ability range.
4. Promotion of positive attitudes to learning in general, and to computers.
5. Promotion of cooperation and good social interactions among children.
6. Achieving good outcomes for both girls and boys.

In brief outline, we worked at a primary school and a secondary school in an industrial suburb of Melbourne. Children had 2 or 3 lessons each week in the computer classroom, usually working 2 to a machine. Classes, typically of size 30, were taken by the regular class teacher, with a variable amount of support by us. We prepared worksheets, which were at first detailed, but later, especially at the older ages, introduced projects that called for student initiative. Activities were in a wide variety of curriculum and non-curriculum areas; children worked with maps, stories, databases, and much besides. Children explored pre-written MITSI programs, extended programs, and built their own programs. We encouraged teachers to concentrate on the activities, the thinking, and the topic area, rather than on the computing.

Our evaluations are based on a wide variety of paper-and-pencil measures of general abilities, computer abilities, and opinions and attitudes.

Our general conclusion is that well-designed activities based on MITSI are very well received by learners and teachers, and can give valuable learning outcomes (Cumming & Abbott,1988b). Vital considerations are the detailed characteristics of the MITSI tool, selection and design of the learning activities, and the stress that is placed on general cognitive abilities. In the remainder of this paper we enlarge on these points.

## 1. THE ACTIVITIES, OR THE COMPUTING?

### 1.1 To teach thinking, teach thinking!

It is now a well supported conclusion that the best way to promote higher cognitive abilities is to address and practise them directly and consciously. The best way to 'train the mind' is not to teach Latin, but to decide more specifically which higher abilities 'training the mind' refers to, and then to work on these in a variety of application areas. This should be done openly: it is important that learners are aware of and can discuss their thinking. So metacognition, or 'thinking about thinking', becomes the aim; it is most likely to be achieved if it is explicitly modelled and encouraged and discussed.

Our conclusion is commonplace, but central and vital: the key to good activities is the discussion and thinking they can spark, and this depends as much on the way they are presented and supported in the classroom as on the details of the computing. More precisely, it is necessary, but a long way from sufficient, to have a powerful and easy-to-use KBS like MITSI. In addition good materials, support and follow-up are needed and must be the main concern of any teacher. (From now on 'teacher' should be taken as shorthand for curriculum designer, mentor, advisor or resource person.)

### 1.2 Get the balance right

The computing details inevitably loom large, especially at first. It is the teacher's job to keep the focus as much as possible on the activities and the thinking. The balance between the two will change over time and also look different from the points of view of teacher and learner.

The teacher needs to have basic MITSI skills (2.1, 2.2 below), and choose worthwhile activities appropriate for this tool (2.4). This requires attention to the computing details. The learners will sometimes need to attend fully to MITSI details, but they should as much as possible be concentrating on the activities, picking up MITSI knowledge incidentally as it is needed.

## 2. MITSI, THE KBS TOOL

### 2.1 The user needs a good mental model

In general, the KBS itself, and the way it is introduced should together promote in the user a good mental model of the system and what it can do. Learners need such a model, and need to feel secure with the mechanics of using the computer and the tool before they can be freed to think about the subject matter. The user's mental model needs to be carefully developed by a combination of experience with programs, and discussion and elucidation.

### 2.2 MITSI is a good KBS

A well-designed KBS is the basis for a good mental model. To the extent that KBS design is less than ideal, errors and frustration will be greater, and learners - especially learners who are young, or of lower ability - will have less capacity available for the main task: the activities themselves. It is worth experimenting and taking great care to get even tiny details of the KBS right. The aim should be to have the KBS as close as possible to invisible

After some initial trials with the SIMPLE syntax (Ennals, 1983), we changed to MITSI (Briggs, 1984; Abbott & Cumming, 1987; Cumming & Abbott, 1988a). We have since extended the original MITSI considerably and now use it in all our work. It is the basis for the materials we are currently preparing for publication (Cumming & Abbott, in preparation). We are also working with Jonathan Briggs as he develops the definitive version of MITSI (Briggs, 1988).

Features of MITSI that contribute to its suitability for children's use include:
1. The binary infix format is simple and consistent, yet, especially with the use of lists, powerful.
2. This format, and the use of _some... and _any... as variable names, allow similarity to English to be helpful without being misleading.
3. Use of !, ., and ? for commands, adding and queries gives a natural way to distinguish and indentify these functions.
4. The syntax is sparse and natural, and so easy to learn and use.
5. The seek facility, together with querying, makes it easy to explore an unknown program in a flexible way.
6. Explanations revealing the full inference tree are presented in a way that is easily understood.

7. Detailed error messages not only diagnose a problem but hint at how to fix it.
8. Screen layout helps keep different things - such as user input, fragments of program, answers to queries, and instructions from MITSI - conceptually distinct.

### 2.3 Keep quiet about the computing

Sometimes, especially near the start, computing things will need explicit attention from learners. But just because 2.2 above is lengthy does not mean that computing things have centre stage. As we said earlier, attention should as much as possible be on the activities and the thinking.

### 2.4 Choose activities that suit the tool

We have used a wide variety of types of activities, and keep thinking of new ones. But beware of claims that are too sweeping! Different tools have their various strengths and weaknesses. Given that the emphasis is on worthwhile educational activities, MITSI should be used for things that it is good for. For other things, use another way.

MITSI is a good tool for a broad range of information-handling activities, including those in which the focus is on:
1. Transferring information between a program and a map or diagram.
2. Exploring information in a program, to discover things, solve a mystery, or understand the topic better.
3. Databases, either using them or building them.
4. Exploring and expressing simple logical relationships among items.
5. Working with a topic that has a rule-like structure.
6. Organising a body of knowledge, and expressing it in a systematic and rule-bound way.

MITSI is not so naturally suited for (take this list as a challenge if you wish!):
1. Complex calculations, and spreadsheet representations.
2. Sequential processing, as needed for many simulations.
3. Graphics and complex screen displays.
4. Working with emotional, expressive language and literature.
5. Representing a body of knowledge that is unsystematic, or variable, or uncertain. (See also 3.8 below.)
6. Telecommunications.

## 3 DESIGNING ACTIVITIES

### 3.1 Start top-down

It is fashionable to advocate giving learners the tool, and the freedom to do what they will. This is a 'bottom-up' approach, in that it starts with learning the syntax and building programs. A 'top-down' approach, by contrast, starts with learners using pre-written programs: they explore them, then modify and extend them, and only later start to build their own programs. We have compared parallel classes using top-down and bottom-up approaches, and found evidence that it is more effective to start top-down.

Working first with complete programs seems to give learners more coherent and interesting activities at the start, and allow them to learn about MITSI gradually and in context. Learners seem better motivated, and they develop their mental models of the whole system more naturally.

Bottom-up and top-down styles each has its value, and many activities combine features of both. Our advice is simply that top-down should predominate early on.

### 3.2 At the start, it can never be too simple

Material can never be too easy and supportive at the start. Even 15 year olds benefit from a great deal of hand-holding, and enjoy using quite restricted programs to build up their confidence. Much can be done with simple mystery programs that contain facts, and few or no rules. The simple structure enables a great deal of thinking and exploration to occur. Older learners move rapidly on, but younger users happily repeat programs: much experience is necessary before confidence can develop.

### 3.3 Start detailed, go project

It is fashionable also to stress that the learner should be in control and free to use initiative, and to decry the restrictiveness of structured worksheets. In practice, applying these noble sentiments at the start usually leads either to frustration and break-down, or to the need for vast amounts of individual help.

Worksheets are an efficient way to cope with classroom realities, and to give children the maximum scope to work at their own pace. The teacher is largely freed to work with individuals having special problems. Worksheets need to be sufficiently detailed to enable most to work independently, but open enough to encourage exploration and discovery.

At the start worksheets can be very detailed and directive (3.2 above), while still offering optional detours and extension activities. They should become progressively more sketchy as learners develop their skills, ideas and initiative. The progression to project work is of course much faster with older learners.

Structured worksheets also give extra support to teachers. Teacher ability and confidence with the syntax is important, but, even so, this structure can be useful for teachers who are relatively unfamiliar with the use of computing tools to promote learning.

Higher skills worth promoting include many that are needed to use worksheets independently. These skills usually require deliberate attention and development, but their generality makes the effort worthwhile. Children need to be able to read the screen and the worksheet carefully, relate the two, and think of possible next steps. The strategy of using a previous question to help with a current one usually needs specific coaching. Persistence, consideration of alternatives and discussion with others are all important. Some of the most enthusiastic reports to us from teachers have come from their perception that these sorts of general skills have transferred from MITSI activities in the computer room to the regular classroom.

### 3.4 Curriculum or non-curriculum topics?

The choice is with the user! We have used activities in a broad range of topic areas, many from the curriculum but also many that are not. The nature of the activity, and the structure of the information being dealt with are the important things. Simple non-curricular games, puzzles and mysteries can be engaging for children, while giving great scope for good thinking and discussion. So, use any curriculum topic that is suitable and of interest, but do not hesitate to use a non-curriculum topic if that seems most effective.

### 3.5 Use a big range of activities

Using a variety of types of activities adds interest, allows users to exploit MITSI more fully, and promotes a richer range of general skills. Using any particular type of activity in a variety of topic areas also increases the diversity of learning. A single MITSI program can be used in a variety of ways; this flexibility fits well with the current educational practice of working on a single theme topic across several curriculum areas.

Higher abilities are, by definition, to some extent general. The key to promoting general abilities is to use them in a range of applications, while recognising the commonalities. Therefore, given that our primary focus is on developing higher abilities, it is important to use activities that are diverse both in type and in topic area.

Using the computer across the curriculum is a worthwhile goal, but can be hard to achieve at higher grade levels, where subject specialisation is the norm. Even if MITSI activities are introduced under the heading of computer studies, or of a particular curriculum area, it is often easy to make parallel versions of programs or activities that can be used as the basis for forays into other curriculum areas: the teaching colleague in that area may thus be tempted!

### 3.6 It is hard to build your own

Starting with simple top-down activities is easy and fun, and gives a good basis for more ambitious things. But writing programs is hard, with great scope for error and frustration. The transition from top-down to bottom-up activities needs to be gradual. Much structure and support is needed, error messages and error recovery skills are vital, and learners need to develop strategies for testing and correcting programs. Encouraging a learner to start by building a program similar in structure to one already explored can be a good approach.

But then getting even a simple program to give satisfactory answers to queries can be rewarding, and form the basis for building a more powerful program. The concept of 'process programming', by analogy with process writing, is a useful one. Students may at first be satisfied with anything that works, however limited it may be, but they need to be encouraged to adopt a develop-test-use cycle so that programs develop, reflecting the growing skills and ideas of the builders.

### 3.7 Writing rules is hard

Rules are at the heart of logic programming, and of MITSI. They are the basis for inference, the main thing making MITSI more than a database shell, and the means for rich knowledge representation.

Our learners' first encounter with rules is usually in explanations given by MITSI of how it found an answer to a user query. A simple example could be: **Martin is my-friend because Martin barracks-for North-Melbourne and Martin has-pocket-money more-than-two-dollars.** Given reasonable choices of object and relation names, such an explanation is readily and correctly understood. Learners can also, with some guidance, accept that there is a rule in the program that says something like: **_someone is my-friend if _someone barracks-for North-Melbourne and _someone has-pocket-money more-than-two-dollars.** A program that consists only of rules can be explored using MITSI's automatic 'ask the user' facility, and explanations; this can be a good way to study rules and how they behave.

Writing rules is, by contrast, very tricky. Expressing the rules accurately in English is a task in itself, and then it is necessary to make these fledgling ideas conform to the MITSI syntax. It is important therefore that early attempts are in carefully chosen areas that are familiar and naturally rule based. Detailed guidance is needed. Making workable rules in an arbitrarily chosen topic area can be extremely hard, so having users choose their own topics can be risky. A particular problem is the need to link rules to other rules, and to facts. At a more advanced level, the problem of writing good rules to organise and express a body of information is the general problem of knowledge representation, to which we now turn.

### 3.8 Beware the limits on knowledge representation

One of the important findings of artificial intelligence (AI) research is that knowledge representation is a central issue, and a tough one. Work with KBS tools in education leads to the same conclusion: all available schemes for knowledge representation have severe limitations.

MITSI supports declarative statements of facts, and if-then rules. Usefully complex programs can be made by using lists and large sets of rules that interconnect well. But the basis is still simple backtracking, with explanation by display of the tree of inferences leading to an answer. If-then rules and backtracking can be used for many things, but fall a long way short of offering solutions to the general problem of representing knowledge and reasoning.

Sweeping claims are sometimes made for the educational value of having learners build their own knowledge bases or expert systems. Such bottom-up activities, in which learners make their understanding of a topic explicit by expressing it in the structured form of a program, can certainly be useful. It is, however, hard to see much educational value in trying to represent a knowledge domain with a tool quite unsuited to the fundamentals of the domain, or to the student's conception of the domain.

We should, therefore, be wary of giving the learner complete freedom in choosing the topic and approach to be taken in building a program from scratch. Grappling with the limitations of a KBS tool can be worthwhile but, for learners with anything less than long experience and secure MITSI skills, the risk of frustration and failure is great. Even as experienced curriculum developers we ourselves find it challenging to write good MITSI programs in an arbitrary curriculum area, and sometimes decide that some topic or activity is best left for some quite other approach.

It is also important to keep a clear view of how the simplified, abstracted model of some topic that is incorporated in a program differs from the real world. If the limitations of the KBS tool mean that the model has to be too distorted, it may be of little use, or even be misleading.

More specifically, KBS tools based on Prolog are advocated as useful for developing small expert systems. We have used MITSI in this way, with positive results. But if the examples put forward in support of this approach are examined, only a restricted range of types of expert system is found. There is little beyond natural taxonomies, systems of rules or regulations, fault dignosis, treasure-hunt style mysteries, and some limited forms of advisor. We must conclude, once again, that the activity and topic need to take account of the knowledge representation limitations of the KBS tool; we look forward to the arrival of new tools having even greater power and flexibility.

## 4. THINGS TO WATCH FOR

### 4.1 Find enough time

Valuable learning experiences depend on building and maintaining good skills with the KBS. An obvious and vital ingredient in doing this is the amount of time available. We have found that once a week is of limited value, two sessions each week is acceptable, but three is very much better. Sessions of 45 minutes or more are considerably better than shorter sessions. Vacations and other long gaps are disruptive. The second year gives more value than the first. Working on MITSI activities outside the computer room helps continuity and can increase the value of time at the computer.

Another factor in determining effective time at the computer is the size of group using each machine. Most of our work has used pairs, and this arrangement is often advocated as the best because it promotes cooperative working. Using pairs is an effective arrangement, although personality clashes need to be defused. Children of different ability levels can often work well in a pair, if the difference is not too great.

We have also had some extended experience of a class of 30 using 30 computers, one per student: this unusually luxurious arrangement not only gave very good rates of individual progress but also, with appropriate encouragement, led to a healthy amount of task-related discussion and cooperation.

If there are more than two or three learners per computer, access to the machines should be rotated, or the activities reorganised specifically for group working.

### 4.2 Learners vary: Look beyond the stars

It is another commonplace statement that learners vary greatly in their abilities, preferences and rates of working. Having children work individually or in pairs gives scope for learners to proceed at their own pace, but it can be difficult in practice to handle this variety within a class. Using worksheets with optional detours and extensions can give fast workers worthwhile things to do, while everyone has the chance to cover the core of the activities. It is important to be sensitive to how students at both ends of the ability spectrum are faring.

Some children have particular difficulty getting started, and must have considerable help at first if they are to build their understanding and confidence to a level that can support more independent work. Peer mentoring arrangements offer attractive possibilities.

Our positive conclusions about MITSI are based on findings that learners across the ability range do well, and feel positive about what they are doing. Evaluation of any tool intended for general use should be based on such an assessment of performance across the full ability range: it is unacceptable to rely, as happens too often in the educational computing literature, on anecdotes about possibly star individuals.

### 4.3 Be enthusiastic but sceptical: Why use a computer?

The glamour of new technology and of buzzwords such as 'KBS' can be useful to help arouse enthusiasm, but must not be permitted to cloud the clear vision and sceptical, practical outlook that should always be with the educator. Build on the inspiring things that some learners do, and use in imaginative ways the undoubtedly powerful features that MITSI offers, but continue to ask whether a computer is really the best way to meet a particular educational goal.

### 4.4 Integrate computer work

Most of our MITSI activities have used timetabled periods in the computer room: this arrangement gives learners maximum machine access and encourages cooperation in computer use. Other arrangements have also worked well. For example, having two or three computers in the home classroom allows use of a program as a source of advice or information for the whole class; alternatively, the class members can share the task of building a single large program. Integrating class and computer room work is a good strategy: it gives maximum scope for exploiting MITSI potential in imaginative ways, and of using the computer specifically for those aspects of activities for which it is best.

### 4.5 Look for computer spin-off

Our emphasis on higher abilities and a spread of topics should not completely exclude computer studies. For learners using as well a traditional computer language, familiarity with MITSI gives the opportunity to discuss procedural and declarative representations, and the choice of tool to suit a task. KBS tools can of course be used to illustrate some basic AI ideas; we have used MITSI programs in this way at school and at undergraduate level.

### 4.6 Beware sex-role stereotypes

We have found consistently in our work that girls do at least as well as boys, and feel just as positive about computers and what they are doing. The fact that MITSI activities are most naturally based on language, rather than mathematics or symbols, may be a factor, but we suspect that having sufficient hardware and making computing a standard timetabled part of regular school activities is the key. Avoid, therefore, competition for machine access, and encourage regular class teachers to initiate computer work: in this way girls too should be well served.

## 5 CONCLUDING COMMENTS

### 5.1 Future KBS tools: Beyond MITSI

Powerful computing environments, incorporating things such as windows, mouse, hypertext, and powerful utilities of all kinds, are beginning to appear even in schools. What lies beyond MITSI? Our general conclusions - find or build a tool with excellent design, use it for what it is good for, be imaginative in finding ways to exploit it, and emphasise metacognition - will endure. We will welcome improved interfaces because they will allow us to make the KBS tool closer to invisible: the power of MITSI's rules and explanations will be even more widely usable because more of the user's attention will be available for the topic area activity itself.

Developments in knowledge representation will also be welcome: they will allow programs to be built that are better models of reality, and that venture into more tricky areas of knowledge.

### 5.2 A familiar story?

We conclude that MITSI, our KBS tool, can be valuable for promoting higher general abilities, and that the key to realising the potential is good selection and design of activities, together with good teacher support.

It is interesting to note that the main issues to emerge from research assessing the educational potential of MITSI do not concern the computing details, but rather the enduring issues of curriculum design, imaginative applications, and individual differences among learners.

This conclusion may be unsurprising to thoughtful teachers, but even so it would be useful if it were more widely recognised in the educational computing literature. We would then see less discussion of questions like 'Does Prolog [or Logo, or ... ] experience lead to better problem-solving skills?', and more recognition of the vital issue of curriculum design.

Any assessment allegedly of a computer language or tool must be recognised as being actually an assessment of the whole package: language or tool, teaching approach, activities, topic area, class organisation, and much besides. In these terms, our conclusion becomes that MITSI is a good medium for the development of useful learning activities. Further, these activities should start in a top-down way, be chosen to fit MITSI's strengths, be diverse both in type of activity and in topic area, stress general cognitive abilities, and give scope for learners of all ability levels. Do all this and you can have powerful learning!

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